Low-Temperature Stirling-Cycle Refrigerator for Spacecraft Refrigeration Systems

Douglas G. Westra/ED63
205–544–3120

A Stirling-cycle refrigerator breadboard unit has been built and tested by Stirling Technology Company under a phase II Small Business Innovation Research contract (NAS8–40172). Stirling-cycle refrigeration, offering a viable alternative to the currently used chlorofluorocarbon/ hydrochlorofluorocarbon systems, uses helium as the working fluid and is, therefore, nontoxic to humans and totally harmless to the environment. Stirling-cycle refrigerators can be operated over a wide range of temperatures, have few moving parts, and provide high reliability and low vibration. This technology is applicable to numerous space and commercial refrigeration requirements, including food refrigerator/freezers, laboratory freezers, and freeze dryers, as well as detector and electronics cooling. The refrigerator described herein operates in a temperature range required for food freezers. Consult Walker[1] for a detailed description of the theory and operation behind the Stirling cycle.

The Stirling-cycle refrigerator developed under this project was designed to meet the requirements of the space station food refrigerator/ freezer. The vapor-compression cycle, although very efficient on the ground, has many features that make it less suitable for zero-gravity operation, including a requirement for liquid/ vapor separation in the condenser and a lubricant reservoir. In addition, most manned space applications require high reliability, low vibration, and nontoxic working fluids. Vapor-compression systems, which contain freon refrigerants and have many brazed or soldered connections, must be double- or triple-contained to meet safety standards, thereby decreasing system efficiency. Also, Spacecraft Maximum Allowable Concentration standards often limit the amount of refrigerant that can be used in the system, which sometimes causes further reductions in efficiency and has, in the past, caused intermittent operation (due to frost buildup).

The current baseline technology for the space station food refrigerator/ freezer, thermo-electric, offers many required specifications, including high reliability, low vibration (no moving parts), and no toxicity (no working fluid required). However, it has very low efficiencies (coefficient of performance less than 0.2) and limited capacity. The Stirling-cycle refrigerator provides baseline capabilities with moderate efficiency (coefficient of performance greater than 1.1), and the use of a nontoxic working fluid (helium). In addition, its ability to easily achieve lower temperatures makes it adaptable to other space station applications, including a –70 °C freezer and freeze drier, a –183 °C freezer, and a –196 °C snap freezer.

The unit built by the Stirling Technology Company (fig. 100) has been designed and built to operate at a temperature range and load level needed for typical food freezers and laboratory freezers. This refrigerator makes use of a linear motor, which leads to extremely simple and mechanically compact systems by negating the necessity for converting rotary motion to reciprocating motion. Efficiency and reliability improvements in the linear motor are among the innovations used in this project. Another innovation, the use of flexural bearings, enables the moving components to operate efficiently and without wear, even though a lubricant is not employed. When properly implemented, the forces provided by the flexure totally eliminate the possibility of contact between the moving and stationary parts. Probably the most innovative concept employed is the free-piston Stirling-cycle concept. In this configuration, the moving components within the device are not mechanically coupled to the drive motor via a conventional kinetic linkage; rather, the components (i.e., the displacer) oscillate under the influence of the gas forces occurring within the Stirling cycle.

The internal cycle innovations described above would not have practical benefits without an efficient means of accepting heat from the load to produce cooling while rejecting heat to the heat sink. Consequently, Stirling Technology has also come up with some innovative methods for the heat acceptor (heat load) and the heat rejector (heat sink), including proprietary helium-to-air heat exchangers. For more details of this unit, consult Penswick.[2]

Test results to date have been very promising. The breadboard test unit has supported a heat load of 130 watts at –26 °C (–15 °F) (with a coefficient of performance of 1.1). By simply changing the temperature setpoint, the same unit has achieved a temperature of –70 °C (–94 °F) at a heat load of 60 watts, suggesting that this unit could be used to meet the requirements of the space station laboratory support equipment's –70 °C freezer and freeze drier. Reliability tests on individual components, e.g., the flexures, also show promising results. Subsequent tests are planned to prove the reliability of the entire Stirling-cycle refrigerator system.

[1]Walker, G. *Cryocoolers*, Parts 1 and 2. Plenum Press.

[2]Penswick, B.L. October 24–26, 1995. Long-Life, High-Reliability, Environmentally Sound Electric Generators and Coolers. Presented at the NASA Technology 2005 Conference, Chicago, Illinois.

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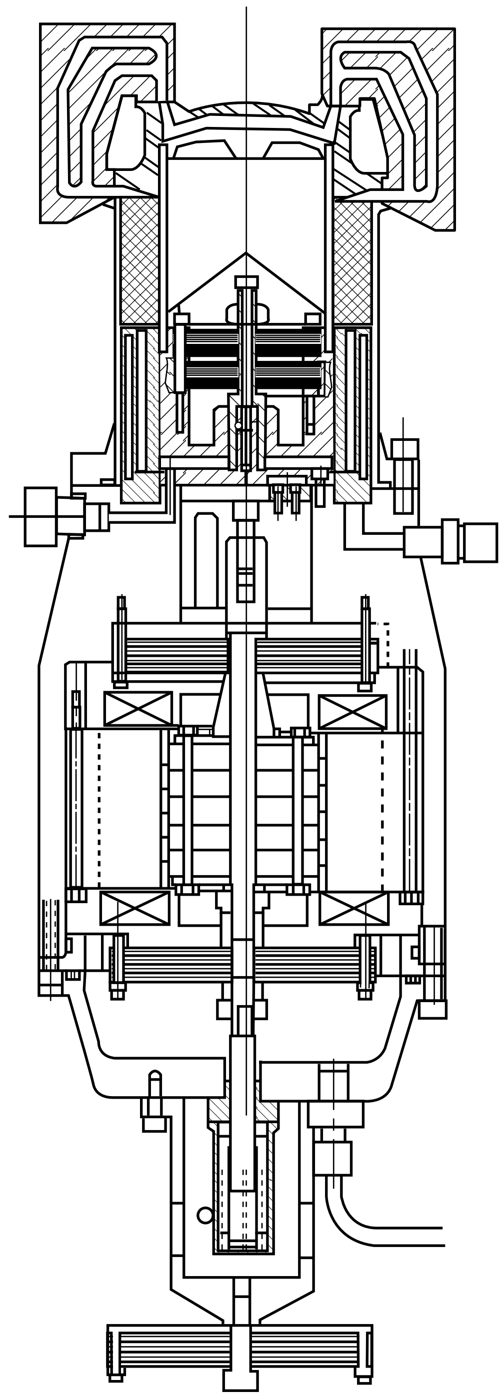

FIGURE 100.—Low-temperature Stirling-cycle refrigerator configuration with advanced cold head (shown vertically).